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Review of RSSI-based Positioning Algorithm and Accuracy

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Abstract: The demand for high-precision, low-cost, and widely used wireless sensor network positioning technology continues to increase, and the algorithms for positioning using wireless sensor networks have been suffering from the problem of insufficient accuracy. This paper introduces and analyzes the steps and principles of the RSSI algorithm, which has low hardware requirements and can achieve high accuracy positioning, and describes the mathematical model and related algorithms used. Finally, we conclude and provide an outlook on the future and development of RSSI.

Keywords: RSSI; Positioning; Accuracy.

1. Introduction

1.1. WSN Positioning

Wireless sensing technology is a rapidly developing technology of information and communication. Currently, the computing and communicating capabilities of wireless sensors are gradually increasing, therefore, WSN, which is composed of multiple wireless sensors, are being more widely used, and their use scenarios have been expanded. An important application is the usage of WSN for positioning, such as satellite positioning and cell phone positioning have become very common, also, various types of positioning methods are used in military, transportation and production [1-2].

The common application scenarios of wireless sensor network localization today are mainly outdoor wide-area localization, such as the localization of vehicles and cell phones, which usually do not have high accuracy; in scientific researches, one of the popular research directions is the positioning of mobile robots and robot crowds, which usually target the positioning of two-dimensional planes. For positioning needs in indoor scenarios, higher positioning accuracy and lower system cost are often required, so positioning solutions used in outdoor environments are not suitable. Indoor localization techniques and localization algorithms have become one of the current research hotspots in wireless sensing technology.

1.2. Positioning Technologies and Algorithms

There are multiple ways of classifying algorithms for positioning techniques, one of the common ones is based on whether the distance between nodes needs to be measured, which divides the algorithms into positioning algorithms based on ranging and positioning algorithms without ranging, the former includes TOA (Time Of Arrival), TDOA (Time Difference of Arrival), AOA (Angle of Arrival), RSSI (Received Signal Strength Indication) and other algorithms, while the latter includes the center-of-mass method, indeterminate algorithm, APIT, DV-Hop and other algorithms. These algorithms have advantages and disadvantages.

This paper analyzes and discusses the RSSI-based positioning algorithm, which is mainly because that the RSSI algorithm meets the low hardware requirements and meanwhile its own characteristics allow it to achieve high accuracy positioning under suitable conditions, which is in line with the development trend of WSN positioning of low power consumption and low cost. In addition, most of today's research on RSSI localization has been improved on the basis of the original RSSI algorithm, which has more optimization directions from the principle, which are analyzed and classified in this paper to provide some entry points and help for others' research.

2. RSSI-based Positioning Algorithm

RSSI-based Positioning Algorithm could be divided into four main steps:

Receive the signals sent by each node.

Calculate the signal attenuation during propagation based on the signal strength values of the transmitting and receiving nodes.

Obtain the distance by using the model equation.

Calculate the location of the node based on the distance using the positioning algorithm.

It can be concluded that the RSSI algorithm is only used for accurate distance measurement in the complete positioning process, and it is combined with other positioning algorithms to derive the exact position of the node.

2.1. Signal Attenuation Model

The RSSI algorithm is an algorithm for distance measuring using the degree of signal attenuation, which requires the use of a signal attenuation model equation to calculate the distance. For empirical models, the more realistic Shadowing Model is generally used, and its expression is expressed as follow:

$$P_r(d) = P_r(d_0) - 10n\lg(\frac{d}{d_0}) + e \quad (1)$$

where d is the distance between the transmitting node and the receiving node, Pr is the signal power received by the receiving node, d0 is the reference distance (generally taken as 1 - 2m), n is the signal loss factor (generally taken as 2 - 4), e is a zero-mean Gaussian random variable representing the interference such as reflection and interference received by the signal during the propagation process.

2.2. Localization Algorithm

Localization using RSSI requires a combination of corresponding localization algorithms. Common localization algorithms include trilateral localization algorithm, weighted center-of-mass algorithm, etc.

2.2.1. Trilateral Localization Algorithm

Assuming that the coordinates of the three known nodes A, B, and C are (x1, y1), (x2, y2) and (x3, y3), and the coordinate of the unknown node P is (x, y), the distances from P to the three known nodes are d1, d2, d3, a system of equations can be established as follows:

$$\begin{cases} d_1 = \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \\ d_2 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} \\ d_3 = \sqrt{(x_3 - x)^2 + (y_3 - y)^2} \end{cases} \tag{2}$$

Solving this system of equations yields the coordinates of point P.

2.2.2. Weighted Center-of-mass Algorithm

In the same assuming scenario as above, according to the general center-of-mass algorithm, introduce a weighting factor k, a system of equations can be created as follows:

$$\begin{cases} x = \dfrac{\frac{x_1}{(d_1+d_2)^k} + \frac{x_2}{(d_2+d_3)^k} + \frac{x_3}{(d_1+d_3)^k}}{\frac{1}{(d_1+d_2)^k} + \frac{1}{(d_2+d_3)^k} + \frac{1}{(d_1+d_3)^k}} \\ y = \dfrac{\frac{y_1}{(d_1+d_2)^k} + \frac{y_2}{(d_2+d_3)^k} + \frac{y_3}{(d_1+d_3)^k}}{\frac{1}{(d_1+d_2)^k} + \frac{1}{(d_2+d_3)^k} + \frac{1}{(d_1+d_3)^k}} \end{cases} \tag{3}$$

3. Improvement of Algorithm Accuracy

3.1. Causes of Errors

Based on the analysis of the steps and principles of the RSSI-based localization algorithm in Section 2, the causes of various aspects that lead to localization errors could be derived. In steps a and b, signals are sent and received through wireless sensors, and propagation losses are inevitably generated during the propagation of electromagnetic wave energy. In addition, this process is subject to interference caused by environmental factors such as temperature and obstacles, resulting in noise and other errors in the data. In step c, a model equation is fitted to obtain the distance, and the accuracy of the fit of the model equation determines the accuracy of the final positioning. In step d, it is necessary to use the positioning algorithm that uses distance for calculation, and then the accuracy of the positioning algorithm directly affects the accuracy of the calculation results.

3.2. Filtering

Filtering is generally an optimization process that reduce the noise and fluctuation of the initial signal in the whole positioning process, so that the obtained signal and the calculated attenuation are more reliable and accurate. Commonly used filtering algorithms include mean filtering, Gaussian filtering and Kalman filtering, etc. Mean filtering is simpler to calculate but the filtering effect is not ideal; Gaussian filtering algorithm is more complicated, but the effect is obvious; Kalman filtering is more suitable for the optimization of motion nodes. In recent studies, some new filtering algorithms have also been used in optimization, such as particle filtering, set-membership filtering, etc.

The positioning process can be optimized by using various filtering methods. Lu et al introduced the ROF model to optimize and improve the Gaussian filter, which solved the problem that the general Gaussian filter could not deal with the numerical error caused by the fluctuation area of high probability data, and made the RSSI smoother. Feng et al used particle filter to observe the position of moving nodes, and then optimized the results of particle filter with Kalman filter to achieve the prediction of the motion trajectory of moving nodes and real-time positioning. Wang used set-membership filtering and combined with sequential fusion algorithm to improve the computational efficiency and enable more accurate estimation and localization of moving node positions.

3.3. Algorithm Optimization

The RSSI algorithm itself relies on empirical model equation for computation, and the fitness of the model affects the accuracy of the algorithm. Therefore, an entry point for improving the algorithm arises. In some studies, researchers perform different ways of optimization in this step to obtain as accurate distance values as possible when converting the RSSI values sent by nodes into distance calculations. Anbalagan Loganathan et al. designed an algorithm to filter RSSI values using a smoothing metric, establish a curve smoothing formula for the case of uniform node motion, and select the appropriate smoothing value through multiple experiments to estimate the positioning of moving objects. Wu et al introduced a node coverage model and proposed a multi-objective optimization model considering obstacles to improve the effective coverage of WSN. Chen et al proposed a context-adaptive RSSI localization method for indoor complex environments by selecting multiple fitting models, segmenting the filtered data for heterogeneous fitting and calculating the fitting error separately, and selecting the segmentation point with the smallest error as well as the fitting model. These methods improve the adaptability to different environments.

Another aspect is the optimization of the localization algorithm. Since positioning using RSSI requires the assistance of other localization algorithms, there are also many studies that try to improve the accuracy of the localization calculation process. The study by Jiang et al improved the weighted center-of-mass algorithm in the localization phase by using the exponential power of the inverse of the distance as the weight, while using the idea of iteration to maximize the node coverage, which significantly improved the localization accuracy. Nie et al studied the smoothness and distribution properties of RSSI, noting that the probability density function of RSSI approximates a Gaussian distribution, and used Bayesian estimation to obtain each weight in the discrete space and calculated the position with the largest weight as the localization result.

3.4. Algorithm Fusion

RSSI itself has low hardware requirements, but is also susceptible to environmental influences. When hardware conditions allow, RSSI and other algorithms can be combined to complement each other to improve the localization accuracy. For example, Zhang et al used a Gauss-Markov migration model in the face of 3D spatial localization, using RSSI for close-range ranging and TOA for long-range ranging to compensate for the problem that TOA algorithm is prone to excessive errors and RSSI accuracy is greatly affected by the environment when used alone. Wang combined AOA and

RSSI algorithms, and after using various ways to accurately obtain the data obtained from AOA parameters, the Kalman filter is used to combine the AOA and RSSI information to complete the fusion localization.

3.5. Advanced Algorithmic Techniques

With the development of computers, information technology, advanced algorithms, such as computer vision and neural networks, are becoming popular research directions in the computer and information industries and are also able to be applied in wireless sensing and positioning algorithms. For example, BP neural networks were used to optimize RSSI ranging algorithms by Yao et al, a research group that proposed a ranging method that applied a BP neural network model based on the K-means clustering algorithm, divided the distance intervals for the sample data during ranging, fed the classified data into the neural network, built the model and calculated the measured distances. Lou first proposed in her study a propagation model environment parameter adaptive strategy and cluster-based adaptive perception, then proposed a new optimization scheme based on machine learning, joint adaptive algorithm, solving the problem that the general improvement algorithm cannot be applied to the multiple ranging and positioning model and effectively improve the accuracy. Jiang et al chose image processing as the optimization method, then the original signal was subjected to Gaussian filtering, Kalman filtering, After a series of processing such as fingerprint library establishment and K-D tree establishment, the initial localization points are screened out by the improved K-nearest neighbor algorithm, and then image processing is used for localization, which achieves the same accuracy as traditional RSSI positioning with more nodes in the case of fewer nodes and reduces the equipment requirements and algorithm complexity. Irsan Taufik Ali et al selected the DeepFi-LoRaIn technique to train the RSSI values and use the resulting model for location prediction in dynamic environments, which reduces the environmental impact during data collection and improves the localization accuracy.

4. Conclusion

The RSSI-based positioning algorithm has considerable application prospects and conditions for promotion, but due to the characteristics of the algorithm itself, its accuracy problem makes it not yet competent for higher precision work and applications. It is notable that many researchers have improved the RSSI-based positioning algorithm from several perspectives. With the development of technology and the emergence of new algorithms, different kinds of improvements and optimizations are making the ranging accuracy of RSSI and the positioning accuracy with the application of RSSI more accurate, and optimized algorithms with higher accuracy and more application cases will definitely appear in the future.

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